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Part IV

Department of Transportation

Federal Highway Administration

National Standards for Traffic Control Devices

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Parts 625, 646, and 655

[FHWA Docket 80-11]

National Standards for Traffic Control Devices; Manual on Uniform Traffic Control Devices; Railroad-Highway Projects

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Advance notice of proposed rulemaking.

SUMMARY: This document solicits comments on the following two items relative to railroad-highway crossings.

Item I. As a result of an advance notice of proposed rulemaking (ANPRM) published in the **Federal Register** on August 10, 1978 (FHWA Docket 78-13) the FHWA is considering revising Part VIII of the Manual on Uniform Traffic Control Devices (MUTCD) to include national criteria for the selection of specific highway traffic control systems at railroad-highway crossings. Three alternative methods or options are presented for revising Part VIII as follows:

(a) The establishment of national criteria expressed as a baseline hazard index.

(b) The establishment of criteria for selecting specific traffic control systems at railroad-highway crossings based on a quantitative approach. This procedure would involve the computation of hazard index levels and their comparison to development threshold values.

(c) The establishment of criteria based on a descriptive approach. This method would include a listing of descriptive factors which would be utilized in the selection of highway traffic control systems for installation at railroad-highway crossings.

Item II. The FHWA is also considering the desirability of revising Part VIII of the MUTCD to eliminate the use of flashing light signals without the use of automatic gates.

DATES: Comments must be received on or before September 10, 1980.

ADDRESS: Submit written comments, preferably in triplicate, to FHWA Docket No. 80-11, Federal Highway Administration, Room 4205, HCC-10, 400 Seventh Street, SW., Washington, D.C. 20590. All comments received will be available for examination at the above address between 7:45 a.m. and 4:15 p.m. ET, Monday through Friday. Those desiring notification of receipt of comments must include a self-addressed, stamped postcard. The MUTCD is available for inspection and copying as prescribed in 49 CFR Part 7, Appendix D. It may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 ($18.00).

FOR FURTHER INFORMATION CONTACT: Mr. Justin True, Office of Traffic Operations, (202) 426-0411, or Virginia Cherwek, Office of the Chief Counsel, (202) 426-0786, Federal Highway Administration, 400 Seventh Street, SW., Washington, D.C. 20590. Office hours are from 7:45 a.m. to 4:15 p.m. ET, Monday through Friday.

SUPPLEMENTARY INFORMATION: The FHWA prepares and issues the national standards for traffic control devices used on all streets and highways open to public travel. These standards are published in the MUTCD which has been incorporated by reference into title 23, Code of Federal Regulations, Parts 625 and 655. The FHWA both receives requests and initiates recommendations for changes to the MUTCD.

Part 646, Subpart B and Part 924 of title 23, Code of Federal Regulations, contain policies and procedures pertaining to Federal-aid projects involving railroad facilities.

This ANPRM is being issued so that interested persons and organizations may have an opportunity to participate by commenting on proposed changes to the MUTCD. Based upon the comments received and its own review, the FHWA will prepare a notice of proposed rulemaking for those changes that the agency proposed to make in the MUTCD. Any final changes which result from that action will be published in the **Federal Register** and incorporated by reference in title 23, Code of Federal Regulations.

In this ANPRM there is frequent reference to hazard level and hazard index. These refer to a computed prediction of expected accidents at a particular crossing expressed in terms of accidents per year. A hazard index of 0.05 would describe a situation where one accident is expected every 20 years. Several hazard index formulas are in use by highway agencies. A procedure developed by the Department of Transportation (DOT) is explained in Appendix A.

Discussion of Comments on Previous ANPRM

A prior ANPRM developed by the FHWA appeared in the **Federal Register** on August 10, 1978, at 43 FR 35491, FHWA Docket 78-13, inviting interested persons to comment specifically in regard to the following questions:

1. Should the FHWA in cooperation with the Federal Railroad Administration develop uniform criteria for the selection of highway traffic control systems at railroad-highway grade crossings?

2. What specific factors and conditions should be considered for the several types of warning devices used at grade crossings?

3. Are there any other pertinent comments concerning the development of criteria for the installation of traffic control systems at railroad-highway grade crossings?

A total of 77 written responses was received from the following five groups:

Respondent group	Number of responses
State Highway/Transportation Departments	32
Local/County Governments	11
Public Utility/Service Commissions	6
Railroads	15
Organizations and individuals	13
Total	77

In analyzing the results, nine of the 77 responses were not used, as two railroad respondents and seven individuals did not address the questions posed. The remaining 68 responses to the first question concerning the desirability of developing uniform criteria were classified as follows:

(a) Respondent favors the establishment of uniform criteria.

(b) Respondent favors criteria, provided the criteria would allow some flexibility at the local level. Some examples of flexibility would be recommendations of a diagnostic team, or consideration of such factors as hazardous materials traffic or other factors that might be pertinent at an individual crossing.

(c) Respondent opposes uniform criteria.

Table 1 presents a summary of the responses of each of the five groups classified by the three different types of responses.

Table 1.—*Summary of Responses to Question No. 1*

Responding group	Favor uniform criteria	Favor criteria that provides flexibility	Oppose uniform criteria
State Highway/ Transportation Departments	14	11	7
Local/County Governments	7	1	3
Public Utility/Service Commissions	0	1	5
Railroads	5	2	6

Table 1.—*Summary of Responses to Question No. 1*—Continued

Responding group	Favor uniform criteria	Favor criteria that provides flexibility	Oppose uniform criteria
Organizations and individuals	5	1	0
Totals	31	16	21

Forty-seven, or 69 percent, of those responding favored development of uniform criteria or the development of criteria that would allow some flexibility at the local level of decisionmaking. Twenty-one, or 31 percent, of those responding were opposed to the development of uniform criteria; in other words, it would appear they are satisfied with the existing method of determining the type of highway traffic control system to be installed at a particular railroad-highway crossing.

The second question posed in the previous ANPRM requested information on specific factors and conditions that should be considered in determining the type of highway traffic control systems to be installed at railroad-highway crossings. Table 2 presents a summary, including frequency, of the factors suggested by the respondents which should be considered in determining the type of highway traffic control systems to be installed at railroad-highway crossings. Table 2 also identifies the factors that are presently included in the U.S. DOT–AAR* National Rail-Highway Crossing Inventory.

* Association of American Railroads.

Table 2.—*Summary of Responses to Question No. 2*

Factors suggested for use in determining type of traffic control systems	Number of respondents suggesting
Number of vehicles per day [1]	41
Number of trains per day [1]	40
Sight distance	35
Train speed [1]	34
Accident history [2]	30
Vehicle speed	30
Number of (school) buses/passengers	23
Number of tracks [1]	23
Type of railroad movement (switching, through trains, etc.) [1]	16
Vertical/horizontal alignment of highway	16
Number of passenger trains/passengers	16
Adjacent intersection [1]	15
Number of trucks [1]	14
Number of highway lanes [1]	13
Hazardous materials potential on highway	12
Vertical/horizontal alignment of railroad	11
Existing warning devices [1]	10
Crossing angle [1]	10
Hazardous materials potential on railroad	7
Simultaneous railroad movement potential	7
Urban or rural setting [1]	6
Crossing rideability	5

Table 2.—*Summary of Responses to Question No. 2*—Continued

Additional factors with less than five responses
Maintenance costs.
Availability of power. [1]
High speed trains.
Number of night trains. [1]
Train length.
Terrain.
Crossing width.
Local ordinances.
Driver expectancy.
Distractions/obstructions.
Type of device at neighboring crossing.
Projected train and highway volumes.
Weather conditions.
Pedestrian traffic.
Train speed variations. [1]
Emergency vehicle movement.
Maintenance adequacy.

[1] Factors that are included in the U.S. DOT–AAR National Rail-Highway Crossing Inventory

[2] Available in Federal Railroad Administration files regarding train-involved accidents.

The third and last question in FHWA Docket 78–13 requested any other pertinent comments concerning the development of criteria for the installation of traffic control systems at railroad-highway grade crossings.

A number of respondents raised questions in the following areas:

1. The need to provide flexibility in any national criteria.
2. The complexity of the situation resulting in an inability to develop national criteria.
3. The lack of funding for future installations.
4. The problem of liability.

These four points will be addressed in the following paragraphs in a statement-and-answer format.

Statement 1: Sixteen of the respondents agreed with the need to develop uniform criteria for the selection of highway traffic control systems at railroad-highway crossings provided there was some flexibility in the criteria. There was concern that the decisionmaking powers currently being exercised at the State or local level of government will be usurped.

Answer: The development of uniform criteria does not necessarily preclude local flexibility. The alternatives set forth in this ANPRM provide for flexibility depending on the conditions at a particular site.

Statement 2: Several respondents (especially those who oppose development of uniform criteria) felt there were so many factors to consider that national criteria could not be developed and any attempt would be both futile and meaningless.

Answer: It is true that there are a great number of factors to consider. However, many of these factors, such as train and vehicular volumes, can be measured. Of the 22 factors mentioned more than five times in response to the previous ANPRM, 11 of them are included in the U.S. DOT–AAR National Rail-Highway Crossing Inventory. Other factors which may not be available on a national basis or which cannot easily be quantified can be evaluated at the local level. Meaningful national criteria can be developed while still providing flexibility at the local level.

Statement 3: Several respondents were concerned that even if uniform criteria were developed there is no assurance that funds will be available in the future for the installation of the highway traffic control systems that the criteria may prescribe.

Answer. There is no assurance that sufficient Federal or local funding to achieve desirable safety levels would be available. Improvements at railroad-highway crossings, as with other capital improvements, will require a systematic establishment of priorities. The establishment of reasonable criteria should assist in the development of priorities and in the definition of program needs at Federal, State and local levels.

Statement 4: Another potential problem cited by several respondents dealt with their liability if an accident occurred at a crossing which had not been improved to the standard called for in the uniform criteria.

Answer. The question of liability is serious, and is not confined to the railroad-highway crossing situation. The FHWA believes that a State or local jurisdiction which establishes a systematic program to meet Federal, State or local standards can successfully defend itself against lawsuits even if all locations have not yet been improved to the established program standards.

National Criteria for Selection of Traffic Control Systems

Item I(a). Proposed Establishment of National Criteria Expressed as a Baseline Hazard Index

There has been a continuing program for safety improvements at railroad-highway crossings for many years. The FHWA is considering the establishment of national criteria which can be quantified so that progress can be measured. One approach is to establish a baseline hazard level or hazard index. The objective would be the development of programs by all highway agencies to reduce the hazard level at all crossings to or below that of the established baseline.

This option would not mandate the type of improvement required at each crossing, but would recognize that various actions could be taken to improve safety conditions at individual crossings and thereby reduce the

existing hazard index. For example, improvements could involve increased sight distances, more effective advance warning treatments, higher quality crossing surfaces, and improved roadway geometrics, as well as the installation of active warning devices. Improvements could be made either singularly or in combination to effect an overall reduction of the hazard index to or below the baseline hazard level established.

Since the specific treatment to be applied to an individual crossing would not be prescribed, responsible highway authorities would be required to establish or estimate the effectiveness of proposed treatments in reducing the existing hazard index and to provide for sufficient improvement to lower the hazard index to or below that of the established baseline.

Several past studies have developed effectiveness values for active traffic control systems. The effectiveness values used in the development of this ANPRM are shown in Table 3.

The hazard index after an improvement can be estimated as follows:

$H_A = H_B (1-E)$

where H_A = Hazard index after improvement
H_B = Hazard index before improvement
E = Effectiveness of improvement which is expressed as the fraction of accidents the improvement is expected to eliminate. See Table 3.

Table 3.—*Effectiveness for Various Traffic Control Systems*

Existing traffic control systems	Effectiveness		
	Improved to flashing lights	Improved to gates	Improved to grade separation
Passive	0.7	0.9	1.0
Flashing lights		0.67	1.0
Gates			1.0

Using this technique it would be possible to determine threshold hazard index levels for each type of active warning device as a function of the baseline hazard index selected. It would also be possible to establish the upper hazard index limit for which gates would reduce the hazard index to the baseline selected. All crossings above that level would require grade separations.

Table 4 has been prepared using data from the U.S. DOT–AAR National Rail-Highway Crossing Inventory. Table 4 shows the number of crossings that would be affected under this procedure and the required improvements for three different baseline levels. The table includes the installation of flashing lights, gates and grade separations but does not consider other improvements such as sight distance improvements or closures.

Table 4.—*Nationwide Actions Required To Reduce All Railroad-Highway Crossings to or Below Various Baseline Hazard Levels*

Baseline hazard level (accid/year)	Action required						
	Passive to grade separation	Passive to flashing lights	Passive to gates	Flashing lights to gates	Flashing lights to grade separation	Gates to grade separation
0.10	2	12,561	595	11,070	2,218	3,164
0.12	2	9,040	296	9,249	1,447	2,129
0.15	2	5,673	104	7,128	812	1,197

For example, referring to Table 4, if a baseline hazard level of 0.12 were established this would require improvements at 22,163 crossings.

Interested persons and organizations are invited to comment in regard to the following:

1. Should national criteria in the form of a hazard level or hazard index be established for the railroad-highway crossing program and included in Part VIII of the MUTCD?

2. Depending on the answer to question 1, what should the value be and what time period should be established to bring all crossings to or below the established baseline hazard index?

3. What is the lowest baseline hazard index which would be prudent and practical?

Item I (b). Proposed Quantitative Procedure for Selecting Traffic Control Systems at Railroad-Highway Crossings

With this approach the determination of the type of highway traffic control system to be installed at railroad-highway crossings would involve the computation of hazard index levels and their comparison to developed threshold values. It is suggested that language similar to the following (indicated by quotation marks) be included in Part VIII of the MUTCD:

"Before any improvement is made at a railroad-highway crossing, an engineering study should be undertaken to determine what actions should be taken to enhance safety at the crossing. The action may include the installation of traffic control systems or other improvements which have a demonstrated capacity to enhance safety and operations at the crossing.

With regard to traffic control systems the following would apply:

(a) As a minimum, crossbucks, advance warning signs, and pavement markings as prescribed elsewhere in Part VIII shall be installed.

(b) The determination of the type of highway traffic control system, other than the minimum as required in paragraph (a) above, at a particular crossing would be a two-step process. The first step would be to calculate a hazard index or hazard level of the crossing in question. The hazard index would be expressed in accidents per year. Using the calculated hazard index and knowing the existing type of highway traffic control system at the crossing, the calculated hazard index is then compared to threshold values in a table to determine the type of traffic control system that should be installed." Table 5 is an example of threshold values which could be utilized. The threshold values shown in Table 5 were calculated on the basis of reducing the hazard index to within a range of 0.08 to 0.12. A description of how these threshold values were calculated is contained in Appendix B.

"TABLE 5.—*Quantitative Procedure*

Existing traffic control device	Calculated hazard index (H)	Recommeded action or improvement
Passive	0.08 to 0.12[1]	See note below.
	0.12 to 0.15	Flashing lights.
	0.15 to 0.23	Flashing lights or gates and flashing lights.
	0.23 to 12.4	Gates and flashing lights.
	12.4 to 18.5	Gates and flashing lights or grade separation.
	greater than 18.5	Grade separation.
Flashing lights	0.12 to 0.18[1]	See note below.
	0.18 to 3.7	Gates and flashing lights.
	3.7 to 5.6	Gates and flashing lights or grade separation.
	greater than 5.6	Grade separation.
Gates	1.32 to 1.98[1]	See note below.
	greater than 1.98	Grade separation.

[1] When the calculated hazard index falls within this range the decision may be do nothing, improve the existing traffic control system, install a different type of traffic control system or make some other improvement at the crossing.

(c) In using the quantitative procedure described in paragraph (b), where a diagnostic team recommends the installation of a traffic control system different from that indicated by the threshold values, or recommends another type of crossing improvement, the recommendations of the diagnostic team shall take precedence over the quantitative procedure.

Other improvements which may be considered for enhancing crossing safety include:

1. Improving sight distances, to detect the presence of the crossing and the train,

2. Closing the crossing,

3. Improving the approach alignment and/or grade of the roadway,

4. Instituting and enforcing railroad and/or highway operating regulations,

5. Improving the crossing surface, and
6. Illuminating the crossing."

The following two examples describe how Table 5 would be used.

Referring to Table 5, assume the calculated hazard index at a crossing is 0.4 and the existing traffic control device at the crossing is "passive." From Table 5, the 0.4 value falls within the range of 0.23 to 12.4, therefore, the recommended improvement would be gates and flashing lights.

Again referring to Table 5, assume the calculated hazard index is 0.10 and the existing traffic control system at the crossing is "passive." The 0.10 value falls within the range of 0.08 to 0.12, therefore, the recommendation would be either to leave the crossing as it is or install flashing lights. The final determination as to the type of traffic control system that would be appropriate for this site would be determined by considering such factors as sight distance, number of school buses, vehicles carrying hazardous materials or other appropriate factors.

It is intended that the quantitative method be flexible and responsive to individual crossing characteristics. Flexibility with the quanititative approach is provided in three ways. First, the engineering study may indicate the need for improvements other than or in addition to traffic control systems. Second, the establishment of ranges in the threshold values where one of two types of highway traffic control systems are recommended provides flexibility. Third, the recommendations of a diagnostic team would override the action recommended by the quantitative procedure.

Interested persons and organizations are invited to comment in regard to the following:

1. Should the quantitative procedure for selecting traffic control systems at railroad-highway crossings be included in Part VIII of the MUTCD?

2. (a) Depending on the answer to question 1, does the approach suggested provide sufficient flexibility for States and local jurisdictions to implement?

(b) If not, what changes should be made?

3. (a) Depending on the answer to question 1, are the suggested threshold values appropriate?

(b) If not, what changes should be made?

Item I (c). Proposed Descriptive Procedure for Selecting Traffic Control Systems at Railroad-Highway Crossings

With this approach the determination of the type of highway traffic control systems to be installed at railroad-highway crossings would be in accordance with a listing of descriptive conditions or factors. It is suggested that language similar to the following (indicated by quotation marks) be included in Part VIII of the MUTCD:

"Before any improvement is made at a railroad-highway crossing an engineering study should be undertaken to determine what actions should be taken to enhance safety at the crossing. Such actions shall include, as a minimum, the installation of adequate warning devices and may include other improvements which have a demonstrated capability to enhance safety and operations at the crossing. The selection of the type of highway traffic control system shall be in accordance with the following:

(a) As a minimum, crossbucks, advance warning signs, and pavement markings as precribed elsewhere in Part VIII shall be installed.

(b) Flashing light signals shall be installed when either of the following conditions exist:

1. There is restricted sight distance in any quadrant at a crossing. In determining the minimum sight triangle the maximum train speed and the larger of the posted highway speed or the 85th percentile speed of highway traffic shall be used.

2. A diagnostic team recommends the installation of flashing light signals.

(c) Automatic gates and flashing light signals shall be installed when one or more of the following conditions exist:

1. Multiple main line railroad tracks.

2. Multiple tracks at or in the vicinity of the crossing which may be occupied by a train or locomotive so as to obscure the movement of another train approaching the crossing.

3. Any crossing of a track with restricted sight distance in any quadrant on which trains operate at 50 mph or more. In determining the minimum sight distance the larger of the posted highway speed or the 85th percentile speed of highway traffic shall be used.

4. Any crossing at which the sight distance is such that the driver of a motor vehicle stopped at the stop line or 15 feet from the nearest rail is not capable of detecting a train in time to avoid a collision before the motor vehicle clears the tracks when proceeding from a stopped condition and operating in a reasonable and legal manner.

5. A combination of high speeds and moderately high volumes of highway and railroad traffic.

6. Either a high volume of vehicular traffic, high number of train movements, substantial numbers of school buses or trucks carrying hazardous materials, unusually restricted sight distance, continuing accident occurrences, or any combination of these conditions.

7. Any crossing with existing flashing light signals which has an accident potential of one accident or more per 10 years as determined by accident history or accident prediction analysis.

8. A diagnostic team recommends the installation of automatic gates and flashing light signals.

(d) Other actions which may be considered for enhancing crossing safety include:

1. improving sight distances, to detect the presence of the crossing and the train,

2. closing the crossing,

3. improving the approach alignment and/or grade of the roadway,

4. instituting and enforcing railroad and/or highway operating regulations,

5. improving the crossing surface, and

6. illuminating the crossing."

Interested persons and organizations are invited to comment in regard to the following:

1. Should a listing of descriptive conditions or factors for the selection of highway traffic control systems at railroad-highway crossings be included in Part VIII of the MUTCD?

2. (a) Depending on the answer to question 1, does this suggested approach provide sufficient flexibility for State and local jurisdictions to implement?

(b) If not, what changes should be made?

3. (a) Depending on the answer to question 1, are the descriptive factors presented adequate and/or appropriate?

(b) If not, what changes should be made?

4. If this approach or the approaches described in Item I(a) on the establishment of a baseline hazard index and in Item I(b) on the establishment of a quantitative procedure as part of the MUTCD are not desirable, is there some other approach for developing national criteria which would be more appropriate?

Item II. Proposed Revision of Part VIII of the MUTCD To Eliminate the Use of Flashing Light Signals Without the Use of Automatic Gates

Sections 8C–2 and 8C–3, Part VIII, of the MUTCD describe the use and operation of flashing light signals. Section 8C–4 discusses automatic gates.

There has been a growing concern that flashing light signals when used without gates are not completely accomplishing their intended function of improving safety at railroad-highway crossings. This concern is supported by the data presented in the report "Rail-Highway Crossing Accident/Incident

and Inventory Bulletin No. 1, Calendar Year 1978" prepared by the Office of Safety, Federal Railroad Administration. Table 23 in this report shows the following:

—Out of a total of 11,999 accidents/incidents involving motor vehicles at public railroad-highway crossings in 1978, 3,779 or about 31 percent occurred at crossings with standard flashing light signals or cantilevered flashing light signals.

—Of the 3,779 accidents/incidents, in 2,400 cases the motorist's action was listed as "did not stop;" in 298 cases the motorists's action was listed as "stopped and then proceeded;" and in the remaining 1,081 cases the motorist's action was listed as "other" or "unknown."

It would appear from the above data that flashing light signals do not guarantee the desired driver response, which is to stop and proceed only when it is safe to do so.

However, the data in Table 23 also show that 1,233 accidents/incidents occurred at public railroad-highway crossings where gates are present. Of these 1,233 accidents/incidents, the motorist's action is listed as follows: in 596 cases "drove around or through the gate;" in 36 cases "stopped and then proceeded;" in 153 cases "did not stop;" and in 448 cases the motorist's action is listed as "other" or "unknown."

Interested persons or organizations are invited to comment on the following:

Should Part VIII of the MUTCD be revised so that flashing light signals can be used only in conjunction with automatic gates?

This advance notice of proposed amendments to the MUTCD is issued under the authority of 23 U.S.C. 109(b) and (d), 315, and 402(a), and the delegation of authority in 49 CFR 1.48(b).

Note.—The Federal Highway Administration has determined that this document does not contain a significant proposal according to the criteria established by the Department of Transportation pursuant to Executive Order 12044. Due to the preliminary nature of this inquiry, a full regulatory evaluation has not been prepared at this time.

Issued on: June 6, 1980.

John S. Hassell, Jr.,

Deputy Administrator.

Appendix A.—Rail-Highway Crossing Hazard Index Prediction Procedure

The purpose of this appendix is to describe a procedure developed by the DOT to predict the hazard index at rail-highway crossings.[1] A crossing's hazard index is defined as the expected number of accidents per year at that crossing. The eight classes of warning devices identified in the DOT–AAR Crossing Inventory [2] have been combined into three categories to simplify the analysis and to realistically reflect the accuracy of the data. These three categories consist of: (1) warning device classes 1 to 4 called "passive" devices, (2) warning device classes 5 to 7 called "flashing lights" and (3) warning device class 8 called "gates." A separate formula is used for each category.

The three hazard formulas have been structured to express the hazard index, H, for the three classes of crossings as the product of a series of factors. Each factor represents a characteristic of crossings described in the DOT–AAR Crossing Inventory. The value of each factor is related to the influence that the corresponding characteristic was found to have in contributing to a crossing hazard index. Only those characteristics that were found to have significant contribution were included in the final formulation. The three hazard formulas are listed below:

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[1] Peter Mengert, "Rail-Highway Crossing Hazard Prediction Research Results," U.S. Department of Transportation, Report No. FRA–RRS–80–02, March 1980.

[2] Warning Device Class 1: No signs or signals.
Warning Device Class 2: Other signs.
Warning Device Class 3: Stop signs.
Warning Device Class 4: Crossbucks.
Warning Device Class 5: Special; e.g., flaggers.
Warning Device Class 6: Highway signal, wigwags or bells.
Warning Device Class 7: Flashing lights.
Warning Device Class 8: Automatic gates.

1. Passive crossings (warning device classes 1 to 4)

$$H_{1-4} = EI_{1-4} \times DT_{1-4} \times MT_{1-4} \times HP_{1-4} \times P_{1-4} \times FC_{1-4}$$

where:

$$EI_{1-4} = 0.389\ e^{1.500X}$$

$$X = -0.137 + 0.381A - 0.668A^2 - 0.192A^3$$

$$A = -3.026 + 1.158 \text{ Log } (T+1) + 0.487 \text{ Log } (C+1) - 0.221\ \overline{/\text{Log } (T+1)/}^2$$

$$DT_{1-4} = (DT+1)^{0.169}$$

$$MT_{1-4} = e^{0.350\ MT}$$

$$HP_{1-4} = e^{0.356\ HP}$$

$$P_{1-4} = e^{0.091\ P}$$

$$FC_{1-4} = e^{-0.263\ FC}$$

2. Crossings with flashing lights (warning device classes 5 to 7)

$$H_{5-7} = EI_{5-7} \times DT_{5-7} \times MT_{5-7} \times P_{5-7} \times FC_{5-7} \times L_{5-7}$$

where:

$$EI_{5-7} = 1.084e^{2.084Y} - 0.195\overline{/\text{Log } (T+1)/}^2$$

$$Y = -2.840 + 0.755 \text{ Log } (T+1) + 0.083\ \overline{/\text{Log } (C+1)/}^2$$

$$DT_{5-7} = (DT+1)^{0.105}$$

$$MT_{5-7} = e^{0.275\ MT}$$

$$P_{5-7} = e^{+0.038\ P}$$

$FC_{5-7} = e^{-0.073\ FC}$

$L_{5-7} = e^{0.036\ L}$

3. Crossings with gates (warning device class 8)

$H_8 = EI_8 \times MT_8 \times L_8$

where:

$EI_8 = 0.154\ e^{1.497Z}$

$Z = -1.967 + 0.186\ \text{Log}\ (T+1)\ \text{Log}\ (C+1)$

$MT_8 = e^{0.383\ MT}$

$L_8 = e^{0.188\ L}$

Symbols

H = Hazard index, accidents per year.

EI = Exposure index.

DT = Number of day through trains.

MT = Number of main tracks.

HP = Highway paved (yes or no?). HP = 1 if paved, 0 if not paved.

P = Population. This is the tens digit of functional classification[1/] of highway over crossing.

FC = Functional class of road. This is the units digit of functional classification[1/] of road over crossing.

L = Number of highway lanes.

T = Number of total train movements.

C = Average daily highway traffic.

1/ Functional classification is a two-digit code contained in the inventory and explained in the Procedures Manual, National Railroad-Highway Crossing Inventory, U.S. DOT-AAR, September 1, 1973.

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The appropriate value used for factors in the hazard prediction formulas are given in Tables A–1 through A–6. Tables A–1 and A–2 are used for the hazard formula for crossings with warning device classes 1 to 4 (formula with subscripts 1–4). Tables A–3 and A–4 are used for warning device classes 5 to 7 (formula with subscripts 5–7), and Tables A–5 and A–6 for warning device class 8 (formula with subscript 8). The first of the two tables that apply to each hazard prediction formula is used to obtain the exposure index (EI), while the second table is used to obtain the values of the other factors. In computing the hazard index, all of the factors contained in the hazard formulas must be considered.

To illustrate use of the formulas and tables in determining the hazard index of a rail-highway crossing, the following example is provided with characteristics which are available from the DOT-AAR Crossing Inventory. The characteristics of the crossing in the example are:

Present warning device	Crossbucks
Annual average daily highway traffic	400
Total number of trains per day	10
Number of day through trains per day	5
Number of main tracks	2
Highway paved?	Yes
Population (thousands)	5–10
Functional class of road	Minor Arterial

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Because this crossing has a class 4 warning device (crossbucks), Tables A-1 and A-2 and formula H_{1-4} are used to calculate the hazard index. First, the exposure index (EI_{1-4}) is found using Table A-1, based on the crossing's highway and train traffic ($EI_{1-4} = 0.12$). Next, the values of the other factors are found using Table A-2: $DT_{1-4} = 1.35$, $MT_{1-4} = 2.01$, $HP_{1-4} = 1.43$, $P_{1-4} = 1.10$, and $FC_{1-4} = 0.35$. The final hazard index is computed by multiplying the exposure index by the other factors as follows:

$$H_{1-4} = EI_{1-4} \times DT_{1-4} \times MT_{1-4} \times HP_{1-4} \times P_{1-4} \times FC_{1-4}$$

$$H_{1-4} = 0.12 \times 1.35 \times 2.01 \times 1.43 \times 1.10 \times 0.35$$

$$H_{1-4} = 0.18 \text{ accidents per year.}$$

TABLE A-1. EXPOSURE INDEX EI_{1-4} - WARNING DEVICE CLASSES 1,2,3,4*

TOTAL TRAINS PER DAY	ANNUAL AVERAGE DAILY HIGHWAY TRAFFIC												
	1-100	101-300	301-500	501-700	701-900	901-1500	1501-3000	3001-5000	5001-7000	7001-9000	9001-15000	15001-30000	>30000
<1	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.06	0.06	0.07	0.08	0.10	0.14
1	0.02	0.03	0.04	0.05	0.05	0.06	0.08	0.10	0.11	0.12	0.14	0.17	0.23
2	0.02	0.04	0.06	0.07	0.07	0.08	0.10	0.13	0.15	0.16	0.18	0.21	0.27
3	0.03	0.05	0.07	0.08	0.09	0.10	0.12	0.15	0.17	0.19	0.21	0.24	0.30
4	0.03	0.06	0.08	0.09	0.10	0.12	0.14	0.17	0.20	0.21	0.24	0.27	0.32
5	0.03	0.07	0.09	0.10	0.11	0.13	0.16	0.19	0.21	0.23	0.25	0.28	0.33
6	0.04	0.08	0.10	0.11	0.12	0.14	0.17	0.20	0.23	0.24	0.27	0.29	0.33
7	0.04	0.08	0.11	0.12	0.13	0.15	0.18	0.22	0.24	0.26	0.28	0.30	0.34
8	0.04	0.09	0.11	0.13	0.14	0.16	0.19	0.23	0.25	0.27	0.29	0.31	0.34
9	0.04	0.09	0.12	0.14	0.15	0.17	0.20	0.24	0.26	0.27	0.30	0.32	0.34
10	0.05	0.10	0.12	0.14	0.16	0.18	0.21	0.24	0.27	0.28	0.30	0.32	0.34
11-20	0.06	0.12	0.15	0.17	0.18	0.20	0.24	0.27	0.30	0.31	0.32	0.34	0.33
21-40	0.07	0.15	0.19	0.21	0.22	0.25	0.28	0.31	0.33	0.33	0.34	0.34	0.31
41-60	0.08	0.17	0.21	0.23	0.25	0.27	0.30	0.33	0.34	0.34	0.34	0.33	0.28
61-80	0.09	0.19	0.23	0.25	0.27	0.29	0.31	0.33	0.34	0.34	0.34	0.33	0.27
81-100	0.10	0.20	0.24	0.26	0.27	0.29	0.32	0.34	0.34	0.34	0.34	0.32	0.26
>100	0.10	0.20	0.24	0.26	0.28	0.30	0.32	0.34	0.34	0.34	0.33	0.32	0.25

*Warning Device Classes: 1 - No signs or signals
2 - Other signs
3 - Stop signs
4 - Crossbucks

TABLE A-2. EXPOSURE INDEX MULTIPLIERS - WARNING DEVICE CLASSES 1,2,3,4

DAY THROUGH TRAINS	DT_{1-4}	MAIN TRACKS	MT_{1-4}	HIGHWAY PAVED	HP_{1-4}	POPULATION (000)	P_{1-4}	HIGHWAY FUNCTIONAL CLASS	FC_{1-4}
0	1.00	0	1.00	No	1.00	<5	1.00	Rural and Urban Interstate	0.77
1	1.13	1	1.42	Yes	1.43	5-10	1.10	Rural Principal and Urban Freeway and Expressway	0.59
2	1.20	2	2.01			10-25	1.20	Rural Minor Arterial and Urban Principal Arterial	0.45
3	1.26	3	2.86			25-50	1.31	Rural Major Collector and Urban Minor Arterial	0.35
4	1.31	4	4.05			>50	1.44	Rural Minor Collector and Urban Collector	0.27
5	1.35	5	5.75					Rural and Urban Local	0.21
6	1.39	>5	8.17						
7	1.42								
8	1.45								
9	1.48								
10	1.50								
11-20	1.60								
21-30	1.74								
31-40	1.83								
>40	1.94								

TABLE A-3. EXPOSURE INDEX EI_{5-7} - WARNING DEVICE CLASSES 5,6,7*

TOTAL TRAINS PER DAY	ANNUAL AVERAGE DAILY HIGHWAY TRAFFIC														
	1-100	101-300	301-500	501-700	701-900	901-1300	1301-1700	1701-2100	2101-2500	2501-3000	3001-4000	4001-5000	5001-6000	6001-7000	7001-8000
<1	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04
1	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06
2	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.08
3	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.10
4	0.01	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11
5	0.01	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.12
6	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13
7	0.01	0.03	0.04	0.04	0.04	0.05	0.06	0.07	0.07	0.08	0.09	0.10	0.12	0.13	0.14
8	0.01	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15
9	0.01	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.10	0.12	0.13	0.14	0.16
10	0.01	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16
11-15	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.16	0.17	0.18
16-20	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.20	0.21
21-25	0.03	0.04	0.06	0.06	0.07	0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.20	0.22	0.24
26-30	0.03	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.13	0.15	0.17	0.19	0.22	0.24	0.26
31-40	0.03	0.05	0.07	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.19	0.22	0.24	0.27	0.29
41-60	0.04	0.06	0.08	0.09	0.11	0.12	0.14	0.16	0.17	0.19	0.21	0.25	0.28	0.30	0.33
61-80	0.04	0.07	0.09	0.11	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.28	0.31	0.34	0.37
81-100	0.05	0.08	0.10	0.12	0.13	0.15	0.17	0.19	0.21	0.24	0.27	0.31	0.34	0.37	0.41
>100	0.05	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.25	0.28	0.32	0.35	0.39	0.42

*Warning Device Classes: 5 - Special protection
6 - Highway signals, wigwags, & bells
7 - Flashing lights

TABLE A-3. EXPOSURE INDEX EI_{5-7} - WARNING DEVICE CLASSES 5,6,7 (CONT.)

TOTAL TRAINS PER PAY	ANNUAL AVERAGE DAILY TRAFFIC												
	8001-9000	9001-10000	10001-12000	12001-14000	14001-16000	16001-18000	18001-20000	20001-24000	24001-28000	28001-32000	32001-40000	40001-50000	>50000
<1	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.09	0.10	0.11	0.13	0.18
1	0.07	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.14	0.15	0.17	0.20	0.29
2	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.22	0.25	0.37
3	0.10	0.11	0.12	0.13	0.15	0.16	0.17	0.19	0.21	0.23	0.26	0.30	0.43
4	0.12	0.12	0.14	0.15	0.16	0.18	0.19	0.21	0.24	0.26	0.29	0.34	0.49
5	0.13	0.14	0.15	0.17	0.18	0.20	0.21	0.23	0.26	0.29	0.32	0.38	0.55
6	0.14	0.15	0.16	0.18	0.20	0.21	0.23	0.25	0.28	0.31	0.35	0.41	0.59
7	0.15	0.16	0.18	0.19	0.21	0.23	0.25	0.27	0.30	0.33	0.38	0.44	0.64
8	0.16	0.17	0.19	0.21	0.23	0.25	0.26	0.29	0.32	0.36	0.40	0.47	0.68
9	0.17	0.18	0.20	0.22	0.24	0.26	0.28	0.31	0.34	0.38	0.43	0.50	0.72
10	0.18	0.19	0.21	0.23	0.25	0.27	0.29	0.32	0.36	0.39	0.45	0.52	0.75
11-15	0.20	0.21	0.23	0.26	0.28	0.31	0.33	0.36	0.40	0.44	0.50	0.58	0.85
16-20	0.23	0.25	0.27	0.30	0.33	0.35	0.38	0.42	0.47	0.51	0.58	0.68	0.98
21-25	0.26	0.27	0.30	0.33	0.36	0.39	0.42	0.47	0.52	0.57	0.65	0.76	1.09
26-30	0.28	0.30	0.33	0.36	0.40	0.43	0.46	0.51	0.57	0.62	0.70	0.82	1.19
31-40	0.31	0.33	0.36	0.40	0.44	0.48	0.51	0.56	0.63	0.69	0.78	0.91	1.32
41-60	0.35	0.38	0.41	0.46	0.50	0.54	0.58	0.64	0.71	0.79	0.89	1.04	1.50
61-80	0.40	0.43	0.47	0.52	0.57	0.61	0.66	0.73	0.81	0.89	1.01	1.18	1.70
81-100	0.44	0.47	0.51	0.57	0.62	0.67	0.72	0.79	0.89	0.98	1.10	1.29	1.86
>100	0.46	0.49	0.53	0.59	0.64	0.70	0.75	0.82	0.92	1.01	1.15	1.34	1.93

TABLE A-4. EXPOSURE INDEX MULTIPLIERS - WARNING DEVICE CLASSES 5,6,7

DAY THROUGH TRAINS	DT_{5-7}	MAIN TRACKS	MT_{5-7}	LANES	L_{5-7}	POPULATION (000)	P_{5-7}	HIGHWAY FUNCTIONAL CLASS	FC_{5-7}
0	1.00	0	1.00	1	1.04	≤ 5	1.00	Rural and Urban Interstate	0.93
1	1.08	1	1.32	2	1.07	5-10	1.04	Rural Principal and Urban Freeway and Expressway	0.87
2	1.12	2	1.73	3	1.11	10-25	1.08	Rural Minor Arterial and Urban Principal Arterial	0.80
3	1.16	3	2.28	4	1.16	25-50	1.12	Rural Major Collector and Urban Minor Arterial	0.75
4	1.18	4	3.00	5	1.20	>50	1.16	Rural Minor Collector and Urban Collector	0.70
5	1.21	5	3.95	6	1.24			Rural and Urban Local	0.65
6	1.23	>5	5.20	7	1.29				
7	1.24			8	1.34				
8	1.26			>8	1.38				
9	1.27								
10	1.29								
11-20	1.34								
21-30	1.41								
31-40	1.46								
>40	1.51								

TABLE A-5. EXPOSURE INDEX EI_8 - WARNING DEVICE CLASS 8*

TOTAL TRAINS PER DAY	ANNUAL AVERAGE DAILY HIGHWAY TRAFFIC														
	1-100	101-300	301-500	501-700	701-900	901-1500	1501-3000	3001-5000	5001-7000	7001-9000	9001-13000	13001-20000	20001-30000	30001-50000	750000
<1	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
1	0.009	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.012
2	0.010	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.013	0.014	0.014	0.014	0.015	0.015	0.016
3	0.010	0.012	0.013	0.013	0.013	0.014	0.014	0.015	0.015	0.016	0.016	0.017	0.017	0.018	0.018
4	0.010	0.013	0.013	0.014	0.014	0.015	0.015	0.016	0.017	0.017	0.018	0.019	0.019	0.020	0.021
5	0.011	0.013	0.014	0.015	0.015	0.016	0.017	0.018	0.018	0.019	0.019	0.020	0.021	0.022	0.023
6	0.011	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.020	0.020	0.021	0.022	0.023	0.024	0.026
7	0.011	0.014	0.016	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.022	0.023	0.025	0.026	0.028
8	0.011	0.015	0.016	0.017	0.018	0.018	0.020	0.021	0.022	0.023	0.023	0.024	0.026	0.028	0.030
9	0.011	0.015	0.017	0.018	0.018	0.019	0.021	0.022	0.023	0.024	0.025	0.026	0.028	0.029	0.032
10	0.011	0.016	0.017	0.018	0.019	0.020	0.021	0.023	0.024	0.025	0.026	0.027	0.029	0.031	0.034
11-20	0.012	0.018	0.019	0.021	0.021	0.023	0.025	0.027	0.029	0.030	0.031	0.033	0.035	0.038	0.042
21-40	0.015	0.021	0.024	0.026	0.027	0.029	0.032	0.036	0.040	0.041	0.043	0.046	0.050	0.055	0.062
41-60	0.016	0.024	0.028	0.030	0.032	0.035	0.040	0.045	0.050	0.052	0.055	0.059	0.066	0.072	0.082
61-80	0.016	0.027	0.031	0.034	0.036	0.040	0.045	0.052	0.059	0.061	0.065	0.071	0.078	0.087	0.101
81-100	0.016	0.028	0.034	0.037	0.040	0.043	0.050	0.058	0.066	0.068	0.073	0.081	0.089	0.100	0.116
>100	0.017	0.029	0.035	0.038	0.041	0.045	0.052	0.061	0.069	0.072	0.077	0.085	0.093	0.106	0.123

*Warning Device Class 8 - Automatic gates.

TABLE A-6. EXPOSURE INDEX MULTIPLIERS - WARNING DEVICE CLASS 8

MAIN TRACKS	MT_8	LANES	L_8
0	1	1	1.21
1	1.47	2	1.46
2	2.15	3	1.76
3	3.15	4	2.12
4	4.62	5	2.56
5	6.78	6	3.08
>5	9.95	7	3.72
		8	4.49
		>8	5.42

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Appendix B.—Hazard Index Thresholds

This appendix contains a description of one method for calculating threshold values. It is not intended that the resource allocation procedure described in this appendix be used as the sole means for determining improvements at railroad-highway crossings. It is included to describe the logic used to calculate the threshold values in Table 5.

A resource allocation procedure has been developed that produces the optimum mix of traffic control systems selection for a given level of funding. This procedure determines which crossings will receive safety improvements consisting of flashing lights, gates or grade separation so as to maximize the benefit in accidents prevented per year for a given funding level. The allocation procedure is applied to a set of crossings until every crossing in the set with a hazard index greater than H_o has been selected for the installation of an active warning device (i.e., flashing lights or gates) or grade separation. The application of the resource allocation procedure to this case can be shown to result in a set of hazard index thresholds which will be used to determine the optimum safety improvement decisions at each crossing. Using the notation—

P=Passive
FL=Flashing Lights
G=Gates
GS=Grade Separation

and assuming that all crossing fall into the three groups—passive, flashing lights, and gates—the following six thresholds are to be determined:

Haxard index threshold	Improvement action
$H_{FL.P}$	Passive to flashing lights.
$H_{G.P}$	Passive to gates.
$H_{G.FL}$	Flashing lights to gates.
$H_{GS.P}$	Passive to grade separation.
$H_{GS.FL}$	Flashing lights to grade separation.
$H_{GS.G}$	Gates to grade separation.

From the resource allocation logic and the warning device parameters, it can be shown that for passive crossings the inequalities $H_{FL.P}]H_{GP}]H_{GS.P}$ hold. The meaning of these thresholds is that if a passive crossing has a hazard index greater than $H_{FL.P}$ but less than $H_{G.P}$, then flashing lights should be installed. If the hazard index is greater than $H_{G.P}$ but less than $H_{GS.P}$, then a gate should be installed. If the hazard index is greater than $H_{GS.P}$, then a grade separation should be constructed.

For flashing light crossings, the inequality produced by the resource allocation logic is $H_{G.FL}]H_{GS.FL}$. Thus, if a flashing light crossing has a hazard index greater than $H_{G.FL}$ but less than $H_{GS.FL}$, then a gate should be installed. If the hazard index is greater than $H_{GS.FL}$, then a grade separation should be constructed.

For gate crossings, there is only one threshold $H_{GS.G}$, corresponding to the fact that there is only one improvement possible. Thus, if the hazard index is greater than $H_{GS.G}$, a grade separation should be constructed.

To calculate these hazard index thresholds the following symbols for effectiveness and cost are used:

Improvement action	Effectiveness	Cost
GS at all crossings	1.0	$1,000,000
P to FL	E_1	C_1
P to G	E_2	C_2
FL to G	E_3	C_3

Note that the cost of constructing a grade separation is assumed to be the same for all crossings. Also, the effectiveness of a grade separation has a value of 1.0 at all crossings.

The approach objective is to install active warning devices or grade separations in the most cost-effective way at all crossings with a hazard index greater than a given baseline hazard index H_o. The logic of the resource allocation procedure is based upon making decisions sequentially from a ranked list of incremental benefit/cost ratios, where benefit is measured in accidents prevented per year. Each ratio on this list corresponds to a warning device decision at a specific crossing with an implied benefit and cost. A cumulative cost is maintained as the algorithm moves down the list and the process is stopped when this cumulative cost equals the given budget level. The decisions that are made as the algorithm proceeds can involve either new crossings or represent a different safety improvement at a crossing previously upgraded. The calculation is stopped and the decisions recorded when the smallest crossing hazard index reaches H_o, the baseline hazard index. As will be demonstrated below, the baseline hazard index always occurs at a passive crossing and the most cost-effective improvement that can be made at passive crossings is installing flashing lights. This leads to the conclusion that $H_{FL.P} = H_o$.

When the allocation procedure is stopped after the last passive crossing with a hazard index greater than H_o is selected for flashing lights, there is no other crossing for which it is more cost-effective to install another safety improvement rather than to install flashing lights at the passive crossing with a hazard index of H_o. For example, there is no crossing which has already been selected for the installation of flashing lights for which it is more cost effective to install gates. One of the thresholds which is to be calculated for the uniform criteria is the hazard index above which gates should be installed at a passive crossing rather than flashing lights (the symbol for this threshold is $H_{G.P}$). In the above example, $H_{G.P}$ is the lowest hazard index for a crossing at which it is more cost-effective to install gates rather than retain a previous decision to install flashing lights when the last passive crossing with a hazard index greater than H_o was selected for flashing lights. The following equation expresses the condition when it would be equally cost-effective to install flashing lights at a passive crossing with hazard index H_o as it would be to change a previous flashing light decision to a gate decision at a passive crossing with hazard index $H_{G.P}$.

Benefit/cost ratio of installing flashing lights at a passive crossing with hazard index H_o equals incremental benefit/cost ratio of installing gates rather than flashing lights at a crossing with hazard index $H_{G.P}$. ($H_{G.P}$ to be calculated from equation.)

This equation can be written using the symbols defined previously as:

$$H_o \times E_1/C_1 = H_{G.P} \times (E_2-E_1)/(C_2-C_1)$$

The benefit/cost ratio on the left side is calculated by the hazard index of the passive crossing (i.e., average number of accidents per year) multiplied by the effectiveness of installing flashing lights (i.e., fractional change in hazard index for installing flashing lights) divided by the cost of installing flashing lights. The right side of the equation is the incremental benefit/cost ratio of installing gates rather than flashing lights at a crossing which originally had a passive warning device. The right side is the hazard index of the originally passive crossing (called $H_{G.P}$ since this is the value of a hazard index which would result in the decision to install gates at a passive crossing) multiplied by the change in effectiveness if gates rather than flashing lights are installed at the crossing (i.e., E_2-E_1) divided by the change in cost of installing gates rather than flashing lights (i.e., C_2-C_1).

The value of $H_{G.P}$ obtained from the above formula is set so that flashing lights will be installed at crossings with hazard index immediately above $H_{G.P}$. The formula states that if it has already been decided to install flashing lights at a passive crossing with a hazard index slightly higher than $H_{G.P}$, then if more money were to be spent it would be most cost-effective to change that decision and install the more costly gates instead, in preference to installing

new flashing lights at another passive crossing with hazard index H_o. However, it would be more cost-effective to install flashing lights at a passive crossing with hazard index H_o than it would be to change a previously made decision to install flashing lights at a passive crossing with a hazard index slightly less than $H_{G.P}$. By the same token, it would be more cost-effective to install flashing lights at a passive crossing with a hazard index slightly higher than H_o than it would be to change a previous decision to install flashing lights to a decision to install gates at a passive crossing with a hazard index equal to $H_{G.P}$. The equation can be solved for $H_{G.P}$ since the values for warning device cost and effectiveness and the value of H_o can be specified.

The previous formula was developed for when it would be as cost-effective to install flashing lights at a passive crossing with hazard index H_o as it woud be to change a previous flashing light decision to a gate decision at a crossing with hazard index $H_{G.P}$. Similarly, equations can be developed for when it is equally cost-effective to install flashing lights at a passive crossing with hazard index H_o as it would be to: (1) install gates at a flashing light crossing with hazard index $H_{G.FL}$, (2) change a previous gate decision to a grade separation decision at a passive crossing with hazard index $H_{GS.P}$, (3) change a previous gate decision at a flashing light crossing with hazard index $H_{GS.FL}$, or (4) install a grade separation at a gate crossing with a hazard index of $H_{GS.G}$. The equations for these conditions containing the other four thresholds are:

$$H_o \times E_1/C_1 = H_{G.FL} \times E_3/C_3$$

$$H_o \times E_1/C_1 = H_{GS.P} = (1-E_2)/(1000-C_2)$$

$$H_o \times E_1/C_1 = H_{GS.FL} \times (1-E_3)/(1000-C_3)$$

$$H_o \times E_1/C_1 = H_{GS.G} \times 1.0/1000$$

The expression on the left side of the equations is the incremental benefit/cost ratio of installing a flashing light at a passive crossing which has a hazard index of H_o. The expression on the right side of the equation, containing a hazard index threshold of the form $H_{A.B}$, is the incremental benefit/cost ratio obtained by installing warning device or grade separation A, in preference to the warning device that is the next less effective one to A, at a crossing which now uses warning device B.

$H_{G.P}$, $H_{GS.P}$, $H_{G.FL}$, $H_{GS.FL}$ and $H_{GS.G}$ can be calculated from the above equations using the values of cost and effectiveness from Table B–1 and specifying a value for H_o.

Table B–1.—*Cost and Effectiveness Parameters for Various Traffic Control Systems*

Improvement action	Effectiveness	Life-Cycle [1] cost ($1000)
Passive to flashing lights	0.7 (E_1)	42.5 (C_1)
Passive to gates	0.9 (E_2)	65.3 (C_2)
Flashing lights to gates	0.67 (E_3)	61.1 (C_3)
Grade separation	1.0	1000.0

[1] Life-cycle costs are based on national averages.

An appropriate range of values for H_o can be specified from the information provided in Figure 1 which shows the cumulative distribution of crossing hazard indices. Figure 1 was developed using data contained in the U.S. DOT–AAR National Rail-Highway Crossing Inventory and the formulas described in Appendix A. The curve in Figure 1 exhibits a sharp knee at a hazard index of about 0.1, with relatively few crossings having a hazard index greater than 0.1. Because of this relationship, rapidly decreasing safety benefits are derived if H_o is specified much less than a value near 0.1. This is the result of high improvement costs (many crossings must be upgraded) while the increase in benefits is diminishing (the crossings being upgraded are less hazardous).

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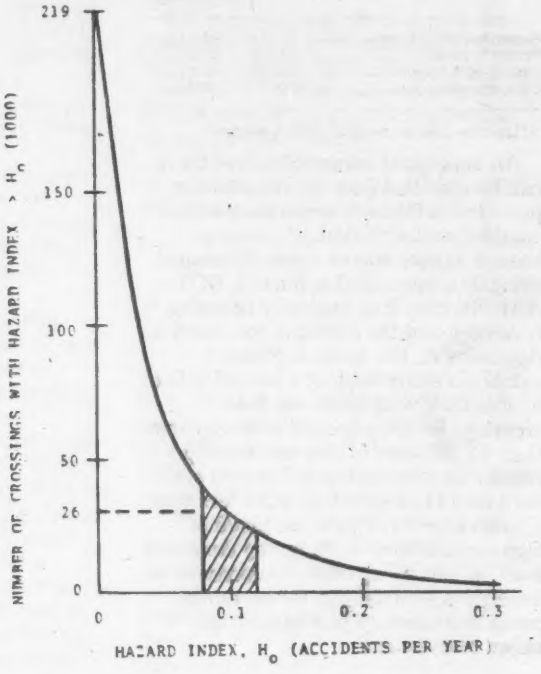
FIGURE 1. CUMULATIVE DISTRIBUTION OF CROSSING HAZARD INDICES



For purposes of establishing national criteria for improving railroad-highway crossings, two values of H_0 were specified to encompass a narrow band around 0.1. The values selected for H_0 were 0.08 and 0.12. Substituting these values of H_0 and the appropriate cost and effectiveness values into the threshold equations defined above produces the following results:

Specified Value of H_0	Hazard Index Thresholds				
	$H_{G,P}$	$H_{G,FL}$	$H_{GS,P}$	$H_{GS,FL}$	$H_{GS,G}$
0.08	0.15	0.12	12.4	3.7	1.32
0.12	0.23	0.18	18.5	5.6	1.98

The above hazard index thresholds were used to develop Table 5, used in Item I(b) of thi-

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